2009

Coordinating service composition

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COORDINATING SERVICE COMPOSITION

The fundamental paradigm shift from traditional value chains to agile service value networks implies new economic and organizational challenges. As coordination mechanisms, auctions have proven to perform quite well in situations where intangible and heterogeneous goods are traded. Nevertheless traditional approaches in the area of multiattribute combinatorial auctions are not quite suitable to enable the trade of composite services. A flawless service execution and therefore the requester's valuation highly depends on the accurate sequence of the functional parts of the composition, meaning that in contrary to service bundles, composite services only generate value through a valid order of their components. We present an abstract model as a formalization of a service value network. The model comprehends a graph-based mechanism design to allocate multiattribute service offers within the network, to impose penalties for non-performance and to determine prices for complex services. The mechanism and the bidding language support various types of QoS attributes and their (semantic) aggregation. We analytically show that this variant is incentive compatible with respect to all dimensions of the service offer (quality and price).

Keywords: Mechanism Design, Coordination, Service Value Network, Pricing Model, Semantics.

The research was funded by means of the German Federal Ministry of Economy and Technology under the promotional reference “01MQ07012”.

1 INTRODUCTION

The paradigm shift from a product- to a service-oriented economy fosters the movement of complete industries from vertical integration to horizontal specialization. Hierarchically organized firms start to cooperate in firmly-coupled strategic networks with stable inter-organizational ties, recently exploring the benefits of moving to more loosely-coupled configurations of legally independent firms. In theory, complex products or services can be produced by a single vertically integrated company. But in this case the company is not able to focus on its core competencies, having to cover the whole spectrum of the value chain. Also, it has to burden all risks in a complex, changing and uncertain environment by itself. This is why companies tend to engage in networked value creation which allows participants to focus on their strengths. At the same time rapid innovation in the ICT sector enables promising opportunities in B2B communication which also supports the current trend. However, especially in complex and highly dynamic industries, forming value networks – especially business webs with their open structure – is more than an attractive strategic alternative. Prominent advocates of this new paradigm are (Tapscott et al., 2000, Hagel III, 1996, Zerdick et al., 2000, Steiner, 2005). As (Tapscott et al., 2000, Steiner, 2005) express it, business webs bring together mutually networked, permanently changing legally independent actors in customer centric, mostly heterarchical organizational forms in order to create (joint) value for customers. Specialized firms co-opetitively contribute modules to an overall value proposition under the presence of network externalities. A prime example for such highly dynamic fields of application is the internet of services. We briefly outline the advantages of business webs related to modularization and specialization (Zerdick et al., 2000): Concentration on core competencies strengthens specialization (C1); Sharing the risk involved (C2); High level of flexibility (C3); Modularization brings potential for innovation and allows for rapid market penetration (C4); Fruitful interplay of competition and partnership (C5).

Auctions have proven to perform well under these conditions to coordinate value generation while addressing mentioned network characteristics. Nevertheless traditional approaches in the area of multiattribute combinatorial auctions are not quite suitable to enable the trade of composite services. Auctions for composite services are much more complex than simple procuring auctions, where the suppliers themselves offer a full solution to the procurer. In composite services, this is not the case, as a flawless service execution and therefore the requester's valuation highly depends on the accurate sequence of its functional parts, meaning that in contrary to service bundles, composite services only generate value through a valid order of their components.

As a coordination mechanism in networked economies we propose a multidimensional procurement auction for trading composite services. We present a graph-based model that captures the main components and characteristics of service value networks. Based on this model we introduced a mechanism design that enables allocation and pricing of service components that together form a requested complex service. The mechanism is capable of handling a wide range of aggregation operations for service attributes also supporting rich semantic approaches for dealing with complex non-functional service specifications. Due to the combinatorial restrictions imposed by the underlying graph topology and the absence of capacity constraints, the winner determination problem can be solved in polynomial time which is a crucial issue when it comes to implementing online systems. We furthermore show that the proposed mechanism is individual rational, allocation efficient and incentive compatible with respect to QoS characteristics and prices of service offers. Hence, reporting the true type regarding configuration and price is a weakly dominant strategy for all service providers.

This paper is structured as follows: The next section gives a brief overview over the literature. Section 3 illustrates the idea of on-demand service procurement in networked economies based on an integration scenario from SAP BusinessByDesign. In Section 4 we propose a multidimensional procurement auction for trading composite services based on an abstract model of a service value network. The mechanism comprehends a multiattribute bidding language (Section 4.1) and the central allocation function (Section 4.2). Section 4.3 demonstrates the semantic aggregation of service attributes and the auction conduction by providing a numerical example. An extension regarding service level guarantees and penalties for non-performance is introduced in Section 4.4. In Section 4.5 we analytically show the providers' bidding strategies and valuable properties of proposed mechanism design. Section 5 concludes with a summary, the practical realization of our approach and future work.

2 RELATED WORK

Recently, an enormous body of work has been done that investigates problems of coordination from a game theoretic and computer science perspective (Papadimitriou, 2001). Especially the discipline of mechanism design that focuses on the problem to coordinate self-interested participants in pursuing an overall goal (Nisan and Ronen, 2001). The authors design suitable mechanisms to standard optimization problems in the area of task scheduling and routing. In incentive compatible mechanisms agents are incentivized to choose the strategy of revealing their true type. Incentive compatible mechanisms such as the celebrated Vickrey-Clarke-Groves (VCG) mechanism are firstly introduced and extensively investigated by (Clarke, 1971, Groves, 1973, Vickrey, 1961). It is important to notice that incentive compatibility in VCG-based mechanisms may fail in repeated games (Binmore and Swierzbinski, 2000) due to the possibility to learn from past situations and adjust ones strategy in a trial-and-error process.

Most of the research has been done with respect to truth-telling of one-dimensional types. The field of designing incentive compatible mechanisms, that induce truth-telling of multidimensional properties of goods or services, still lacks deeper research. A thorough analysis and investigation in the area of multidimensional auctions and the design of optimal scoring rules has been done in (Branco, 1997, Che et al., 1993). In (Bichler and Kalagnanam, 2005) the winner determination problem in configurable multiattribute auctions is investigated from an operational research perspective without accounting for mechanism design aspects such as incentive compatibility. In (Parkes and Kalagnanam, 2002, Parkes and Kalagnanam, 2005) the authors introduce iterative multiattribute procurement auctions focusing on mechanism design issues and solving the multiattribute allocation problem. Preferences for multidimensional goods and multidimensional types in scoring auctions are extensively investigated in (Asker and Cantillon, 2008) and extended to combinatorial auctions in (Müller et al., 2008). Nevertheless their work does not consider value chains and sequences of services as well as their technically feasible interrelations in order to coordinate value generation in service networks. All of these approaches assume bundles of goods in scenarios where the sequence and order does not matter and therefore cannot be applied to composite services that only fulfil their objectives in the right sequence of execution.

Nevertheless, combinatorial auctions yield major drawbacks regarding computational feasibility that result from an NP-hard complexity. Computational feasibility implies a trade-off between optimality and valuable mechanism properties such as incentive compatibility. Several authors propose approximate solutions for incentive compatible mechanisms to overcome issues of computational complexity (Nisan and Ronen, 2007, Ronen, 2001, Ronen and Lehmann, 2005). Path auctions as a subset of combinatorial auctions reduce complexity through predefining all feasible service combinations in an underlying graph topology and are investigated in (Archer and Tardos, 2007, Feigenbaum et al., 2006, Hershberger and Suri, 2001). In their work, path auctions are utilized for pricing and routing in networks of resources such as computation or electricity. Application-related issues of auctions to optimal routing are examined by (Feldman et al., 2005, Maille and Tuffin, 2007). All of these approaches deal with the utility services layer according to the service classification in (Blau et al., 2008) and hence do not cover the problems related to complex services.

3 BUSINESS SCENARIO

To illustrate the idea of a service value network we introduce a business scenario which is actually delivered to customers as part of SAP's BusinessByDesign[1]. The scenario consists of modular service components that can be provided by decentralized service providers. The integration scenario "Service Request and Order Management" (cp Figure 1) describes operational processes in a customer service based on service requests, service orders and service confirmations. From an end-to-end perspective the scenario includes the integration into related applications such as logistics planning and execution, invoicing and payment, as well as financial accounting.

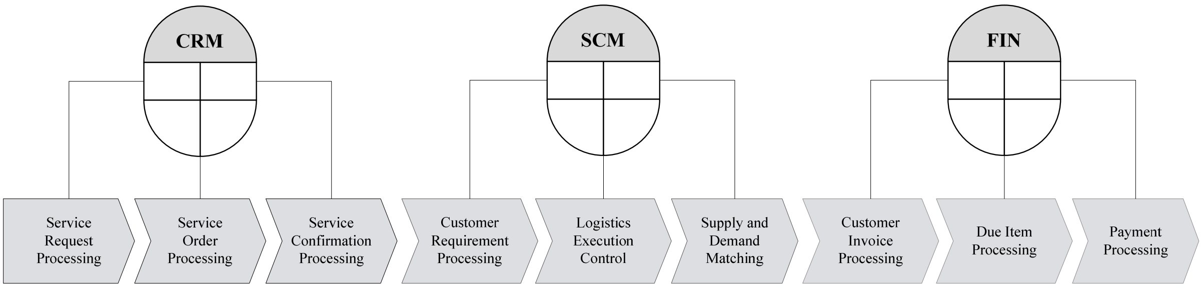

Figure 1 Business Process "Service Request and Order Management"

A *service value network* is formed by many decentralized service providers that contribute to the achievement of an overall goal. In our scenario this goal is the flawless execution of a business scenario in order to provide defined functionality to the customer. From now on we call this overall goal a *complex service*. Recalling the main characteristics of service value networks there are many service providers that offer differentiated and specialized services covering various types of functionality within the network. In our scenario the functionality of each component can be modularized and therefore performed by different software-as-a-service providers as depicted in Table 1. The rapid upcoming of on-demand service providers shows the high degree of innovation and market penetration as a result of modularization (C4). Service providers offer specialized services and concentrate on their core competencies (C1). Each service provider is responsible for a certain part of the overall functionality which consequently spreads the risk of an erroneous business process over all contributing service providers (C2). Furthermore they partly grant access to their own resource supporting the realization of the overall business scenario (C5). The potential of substituting service providers on demand enables flexibility and rapid reaction on changing market requirements (C3).

CRM	**SCM**	**FIN**
Salesforce (http://www.salesforce.com/)	*GXS* (http://www.gxs.com/)	*Cashview* (http://www.cashview.com/)
Rightnow (http://www.rightnow.com/)	*7Hills* (http://www.7hillsbiz.com/)	*Opsource* (http://www.opsource.net/)
Oracle (http://www.oracle.com/crmondemand/)	*Intacct* (http://www.intact.com/)	
SAP (http://www.sap.com/solutions/sme/businessbydesign/)		

Table 1. SaaS Providers for CRM, SCM and FIN Components and their Functional Coverage

[1] http://www.sap.com/solutions/sme/businessbydesign/

4 ABSTRACT MODEL & MECHANISM DESIGN

A service value network is represented by an k-partite, directed and acyclic graph $G = (V, E)$. Each partition $y_1, \dots, y_K$ of the graph represents a functionality cluster that entails services that provide the same functionality (substitutes). The set of N nodes $V = \{v_1, \dots, v_N\}$ represents the set of *service offers* with v is an arbitrary service offer. Services are offered by a set of Q Service Providers $S = \{s_1, \dots, s_Q\}$ with s is an arbitrary service provider. The ownership information $\sigma : S \to V$ that reveals which service provider owns which service within the network is public knowledge. There are two designated nodes v_s and v_f standing for source and sink in the network. The set of M edges $E = \{e_1, \dots, e_M\}$ denotes service compatibilities and interoperabilities such that e_{ij} represents interoperability of service j with service i and their sequence of execution. A service configuration A_j of service j is fully characterized by a set of attributes $A_j = \{a_j^1, \dots, a_j^L\}$ where a_j^l is an attribute value of attribute type l of service j's configuration. Let furthermore $c_{ij}(e_{ij}, A_j)$ denote a cost function that maps service j's configuration to corresponding costs such that $c : E \times A \to R$. c_{ij} denotes costs that the service provider who owns service j has to bear for developing a service that is interoperable with service i (development and production costs) and for performing it during execution (execution costs). Configuration and costs are private knowledge to the service provider who owns a particular service (type). If two services are not interoperable at all, they are not connected within the network. Value is created through the network by performing a sequence of services that form a connected path from source to sink. We call such created value a complex service. Let F denote the set of all feasible paths from source to sink. Every $f \in F$ represents a possible instantiation of the complex service. F_{-i} represents the set of all feasible paths from source to sink without node i and its incoming and outgoing edges. Let F_i be the set of all feasible paths from source to sink that entail node i. In our model we focus on the core process of realizing an overall goal without going into process-related details such as parallel or cyclic components. We apply a business and management-oriented view addressing the question of how an overall goal can be achieved maximizing the systems welfare and to dynamically determine prices.

4.1 Bidding Language

As a formalization of information objects which are exchanged during auction conduction we introduce a bidding language based on bidding languages for products with multiple attributes as discussed in (Engel et al., 2006). Our formalization is aligned to multiattribute auction theory as presented in (Parkes and Kalagnanam, 2002, Ronen and Lehmann, 2005) and assures compliance with the WS-Agreement specification in order to enable realization in decentralized environments such as the Web.

A service requester wants to purchase a complex service f which is characterized by a configuration $\mathcal{A}_f$. The importance of certain attributes and prices of a requested complex service is idiosyncratic and depends on the preferences of the requester. The requester's preferences are represented by a utility function $\mathcal{U}$ of the form:

(1) $$\mathcal{U}_f(\alpha, \Lambda, \mathcal{A}, \mathcal{P}) = \alpha S\left(\mathcal{A}_f\right) - \mathcal{T}_f$$

$\mathcal{T}_f$ denotes the sum of all transfer payments the requester has to transact to service providers that contribute to the complex service such that $\mathcal{T}_f = \sum_{e_{ij} \in f} t_j$. The configuration $\mathcal{A}_f$ of the complex service is the aggregation of all attribute values of contributing services on the path f such that

$\mathcal{A}_f = (\mathcal{A}_f^1, \ldots, \mathcal{A}_f^L)$ with $\mathcal{A}_f^l = \oplus_{e_{ij} \in f} a_j^l$. The aggregation of attributes values depends on their type (i.e. encryption can be aggregated by an AND operator whereas response time is aggregated by a sum operator). Different methods for aggregating service attributes are presented in Section 4.3.

The scoring rule $S\left(\mathcal{A}_f\right) = \left(\sum_{l=1}^{L} \lambda_l \left\|\mathcal{A}_f{}^l\right\|\right)$ represents the requester's valuation for a configuration $\mathcal{A}_f$ of the complex service represented by path f. The scoring rule is specified by a set of weights $\Lambda = \{\lambda_1, \ldots, \lambda_L\}$ with $\sum_{l=1}^{L} \lambda_l = 1$ that defines the requester's preferences of each attribute type analog to the definition of scoring rules in (Asker and Cantillon, 2008). To assure comparability of attribute values from different attribute types the aggregated attribute values $\mathcal{A}_f{}^l$ are mapped on an interval $[0;1]$. $\mathcal{T}_f$ represents the overall price of the complex service. α can be interpreted as the willingness to pay for a optimal configuration $S\left(\mathcal{A}_f\right) = 1$ based on the requester's score. In other words α defines the substitution rate between configuration and price based on the requester's preferences.

Definition 1. Multiattribute Service Request

A request for a complex service is a vector of the form

(2) $R := (G, F, \alpha, \Lambda, \Gamma)$

with G represents a complex service network, F represents all feasible paths from source to sink that form a possible instantiation of a complex service, Λ the requester's preferences and α the willingness to pay. Γ denotes the set of lower and upper boundaries for each attribute type.

A service offer consists of an announced service configuration A_j and a corresponding price bid p_{ij} that a service provider wants to charge for service j being invoked depending on the predecessor service i such that $b_{ij}(e_{ij}) = (A_j, p_{ij})$ is a service offer bid for invocation of service j which interoperable with a predecessor service i with $b : E \to A \times R$. A service provider s bids for all incoming edges to every service it owns.

Definition 2. Multiattribute Service Offer

A multiattribute service offer is a bid matrix of the form

(3) $B^s := \begin{cases} b_{ij}(e_{ij}) = (A_j, p_{ij}), & i \in \tau(j), j \in \sigma(s) \\ 0, & \text{otherwise} \end{cases}$

with $\tau(v)$ denotes the set of all predecessor services to service v with $\tau : V \to V$ and $\sigma(s)$ the set of all services owned by service provider s.

4.2 Mechanism Design

The mechanism maximizes welfare by allocating a path f^* within the service value network that yields the highest overall utility. Let $\mathcal{U}_f$ denote welfare induced by path f with $\mathcal{U}_f = \alpha S\left(\mathcal{A}_f\right) - P_f$.

(4) $o := \operatorname{argmax}_{f \in F} \mathcal{U}_f$

Let $\mathcal{U}^*$ denote the utility of the winning path meaning the utility of a path f^* that maximizes welfare. Let $\mathcal{U}_{-s}^*$ denote the utility of a path f_{-s}^* that yields a maximum overall utility in the reduced graph without every service owned by service provider s and its incoming and outgoing edges.

Every service provider s receives a payment or transfer $t^s = \sum_{i\in\tau(j), j\in\sigma(s), e_{ij}\in f^*} t_j^s$ for all services it owns which are on the winning path. A payment t_j^s for service j corresponds to the monetary equivalent of the utility gap between the "winning path" and "second best path". In other words a monetary equivalent to the utility service j contributes to the systems welfare. This monetary equivalent represents the price that service provider s could have charged without losing her participation in the winning allocation.

(5) $$t_j^s := p_{ij} + (\mathcal{U}^* - \mathcal{U}_{-s}^*)$$

Consequently the payment function t^s for service provider s is defined as

(6) $$t^s := \begin{cases} \sum_{j\in\sigma(s)} \sum_{i\in\tau(j)} p_{ij} + (\mathcal{U}^* - \mathcal{U}_{-s}^*), & \text{if } e_{ij} \in o \\ 0, & \text{otherwise} \end{cases}$$

Costs c^s that service provider s has to bear for performing offered and allocated services result accordingly:

(7) $$c^s := \begin{cases} \sum_{j\in\sigma(s)} \sum_{i\in\tau(j)} c_{ij}(e_{ij}, A_j), & \text{if } e_{ij} \in o \\ 0, & \text{otherwise} \end{cases}$$

The solution to the allocation problem in (4) can be computed in polynomial time using well-known graph algorithms to determine the "shortest" within a network such as the Dijkstra algorithm. Using a Fibonacci heap data structure the time complexity can be reduced to $O(n\log(n)+m)$ with m is the number of edges and n the number of nodes within the graph. According to the payment scheme in (6) the allocation must be computed twice: Based on the graph with the service offerings of the service provider receiving the payment and without its participation. In the second case the graph can be pre-processed and reduced by all service offerings owned by the service provider that receives the payment. After the reduction the shortest path can be computed accordingly which yields the same time complexity. In contrary to the NP-hard complexity in general combinatorial auctions this is a valuable achievement that enables the conduction of our auction in online systems.

4.3 Aggregation and Preference Mapping of Service Attributes

In order to determine the overall score for a provider based on its scoring function, the attribute values of the complex service have to be computed. Recall, the type of function for aggregating attribute value highly depends on the attribute type. Traditional quality of service attributes such as *response time* for example can be aggregated with basic mathematic operations such a sum operator. Table 2 shows different types of aggregation functions for multiple attribute types exemplarily. For example, the overall *throughput* of a complex service that consists of multiple service components is determined by the lowest throughput rate within the allocation and can therefore be computed using a minimum operator.

Attribute Type	**Aggregation**
l	$\oplus^l_{e_{ij}\in f}\, a_j^l$
Response Time (rt)	$\sum_{e_{ij}\in f} a_j^{rt}$
Encryption Type (et)	$\wedge_{e_{ij}\in f}\, a_j^{et}$
Error Rate (er)	$\max_{e_{ij}\in f} a_j^{er}$

Throughput (tp)	$\min_{e_{ij} \in f} a_j^{tp}$
Probability of Default (pd)	$1 - \prod_{e_{ij} \in f} (1 - a_j^{pd})$
Probability of Success (ps)	$\prod_{e_{ij} \in f} a_j^{ps}$

Table 2. Aggregation Functions for Different Types of Attributes

Nevertheless, only considering basic quality of service attributes is not sufficient for dealing with complex non-functional service characteristics that express rich semantic information. The auction mechanism must be capable of aggregating a broad range of descriptive service attributes that express multiple quality aspects. The following example depicted in Figure 2 shows a service value network with four service offers and three possible paths from source to sink (f^{top}, f^{middle}, f^{bottom}).

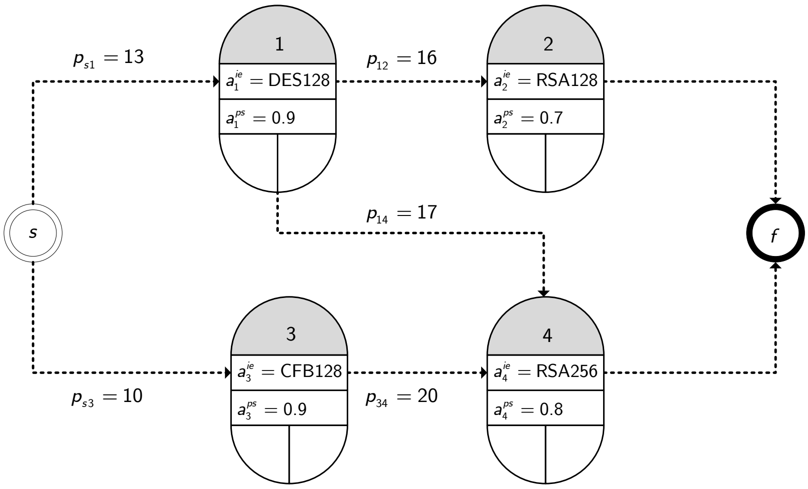

Figure 2 Numerical Example

For simplicity and without loss of generality we assume that each service provider owns only a single service. Price values on the edges represent price bids announced by service providers. Each service configuration consists of attribute values for the types *encryption* (a^{ie}) and *probability of success* (a^{ps}). Attribute values are aggregated according to the aggregation operations in Table 2. Encryption types are derived from the concepts in the *security algorithm ontology* as illustrated in Figure 3.

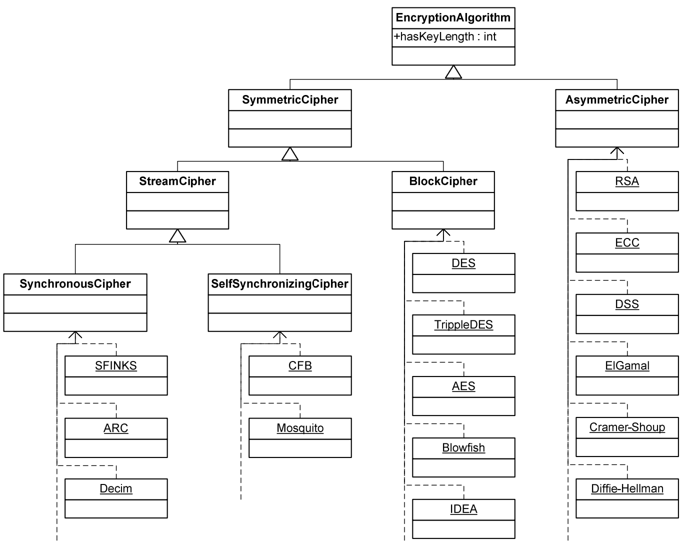

Figure 3 Security Algorithm Ontology

The service requester announces its willingness to pay and weights for each attribute type representing its scoring function such that $\lambda_{ie} = 0.2$, $\lambda_{ps} = 0.8$ and $\alpha = 100$. Furthermore it specifies the *individual encryption* attribute type in first order logic:

$$\begin{aligned}\text{IndividualEncryption}(x) \leftarrow (&\text{BlockCipher}(x) \wedge \text{ hasKeyLength}(x,k) \\ &\wedge \text{isGreaterOrEqual}(k,\text{'128'})) \vee (\text{AsymmetricAlgorithm}(x) \\ &\wedge \text{ hasKeyLength}(x,k) \wedge \text{isGreaterOrEqual}(k,\text{'256'}))\end{aligned}$$

The mechanism allocates service offers on a path from source to sink based on the service request and announced multiattribute offers according to (4). The welfare level, generated by each allocation evolves as follows:

$$\begin{aligned}\mathcal{U}_f^{top} &= 100(0.2(1 \wedge 0) + 0.8(0.9 \times 0.7)) - (13+16) = 21.4 \\ \mathcal{U}_f^{middle} &= 100(0.2(1 \wedge 1) + 0.8(0.9 \times 0.8)) - (13+17) = 47.6 \\ \mathcal{U}_f^{bottom} &= 100(0.2(0 \wedge 1) + 0.8(0.9 \times 0.8)) - (10+20) = 27.6\end{aligned}$$

Therefore f^{middle} is allocated as it yields the highest welfare and each service provider that owns a service on it receives a payment according to (6) such that $t^1 = 13 + (47.6 - 27.6) = 33$ and $t^4 = 17 + (47.6 - 21.4) = 43.2$. The transfer is designed to compensate service providers for their contribution to the system's welfare which implies that i.e. provider 1 could have bid a price of 33 without having lost its participation in the allocation.

4.4 Verification of Service-Level-Agreements

As introduced in Section 4.1 service providers' bids contain a configuration and a price component. The allocation function maximizes welfare based on the achieved quality for the service requester and the costs that occur on the producer's side. This shows that the announced quality also determines the likelihood of being allocated which might induce and incentive for service providers to lie about their configuration. Therefore proposed mechanism is extended with a so called ex-post verification term which is explained in detail in this section.

Let a_j^l be the announced attribute value of attribute type l of service j's configuration. Furthermore let $\tilde{a}_j^l$ be the actual attribute value of attribute type l realized ex-post by service j during execution. $\tilde{\mathcal{U}}_j^*$ is the overall winning path utility with the actual realized attribute values $\tilde{a}_j^1,\ldots,\tilde{a}_j^l$ of service j. Auctioning services based on a platform approach opens up the possibility of ex-post verification. This means that the actual delivered quality of participating services can be measured and monitored after execution. Therefore we can ex-ante enforce a true announcement of quality to be delivered by verifying it ex-post. According to the *Compensation-and-Bonus Mechanism* introduced in (Nisan and Ronen, 2001) a compensation function is constructed as follows

(8)
$$\Delta t_j := \begin{cases}(\mathcal{U}^* - \tilde{\mathcal{U}}_j^*), & \text{if } e_{ij} \in o \\ 0, & \text{otherwise}\end{cases}$$

The compensation function represents the utility gap that results from the utility difference of the announced attribute values and the actual performed ones from the service requester's perspective. In other words the gap that results from the utility loss the systems incurs because of the service provider's untruthful announcement. The monetary equivalent to this utility gap according to the requester's preferences represents the penalty payment the service provider has to bear for deviating from the announced attribute values. This *negative consequence* can be interpreted as a contractual penalty for not realizing specified service-level-agreements as defined in (Salle and Bartolini, 2004). Taking the compensation function into account the payment function is extended as follows:

$$t^s := \begin{cases} \sum_{j\in\sigma(s)} \sum_{i\in\tau(j)} b_{ij}(e_{ij}) + (\mathcal{U}^* - \mathcal{U}^*_{-s}) - \Delta t_j, & \text{if } e_{ij} \in o \\ 0, & \text{otherwise} \end{cases} \tag{9}$$

4.5 An Analytical Analysis of Bidding Strategies of Service Providers

The bidding strategy of each service provider comprehends a price announcement and a corresponding service configuration consisting of a set of attribute values as introduced in the Section 4.1. In this section we analytically analyze providers' bidding strategies in proposed mechanism design:

> **Lemma 1.** *In a Multiattribute Verification Mechanism for each service provider $s \in S$ the reward is independent from its bids consisting of the announced attribute values $a_s^1,\dots,a_s^L$ and the announced prices $p_{ij}\ \forall i \in \tau(j), \forall j \in \sigma(s)$.*

Proof of Lemma 1. Assuming without loss of generality that service provider s only owns one service z with a configuration A_z. F_{-z} denotes the set of all feasible paths from source to sink without service z and its incoming and outgoing edges. We denote f^* as the path which is allocated by o. Let $\mathcal{U}_z^*$ be the utility of path f^* in the graph with service z. Let $\mathcal{U}_{-z}^*$ be the utility of path f_{-z}^* in the reduced graph without service z and its incoming and outgoing edges. Let $\mathcal{U}^*(e_{iz})$ denote the utility of path f^* with $e_{iz} \in f^*$.

$\tilde{\mathcal{U}}_z^*$ is the overall winning path utility with the actual realized attribute values $\tilde{a}_z^1,\dots,\tilde{a}_z^l$ of service z. An invocation e_{ij} of service z is allocated by o iff $\mathcal{U}^*(e_{iz}) \ge \mathcal{U}_{-z}^*$. In this case the profit of service provider s evolves as follows:

$$\pi^s = p_{iz} + t^s - c^s$$

$$\pi^s = p_{iz} + (\mathcal{U}^* - \mathcal{U}_{-s}^*) - \Delta t_z - c_{iz}(e_{iz}, \tilde{A}_z)$$

$$\pi^s = p_{iz} + \left((\mathcal{U}^* - \mathcal{U}_{-s}^*) - (\mathcal{U}^* - \tilde{\mathcal{U}}_z^*)\right) - c_{iz}(e_{iz}, \tilde{A}_z)$$

$$\pi^s = p_{iz} + \left(\tilde{\mathcal{U}}_z^* - \mathcal{U}_{-s}^*\right) - c_{iz}(e_{iz}, \tilde{A}_z)$$

$$\pi^s = \left(\alpha\left(\sum_{l=1}^{L} \lambda_l \left\|\tilde{\mathcal{A}}_z^l\right\|\right) - \sum_{e_{ij}\in f^* | e_{ij} \ne e_{iz}} p_{ij} - \mathcal{U}_{-s}^*\right) - c_{iz}(e_{iz}, \tilde{A}_z) \tag{10}$$

$\tilde{\mathcal{A}}_z^l$ denotes the aggregated and normalized attribute values of type l with the ex-post realized attribute values from service z. Equation (10) shows that once a service z is allocated, its reward is independent from its announced price p_{iz} and all announced attribute values $a_z^1,\dots,a_z^L$. In other words s's bid does not have an impact on the transfer function t^s. □

> **Theorem 1.** *In a Multiattribute Verification Mechanism, for each service provider $s \in S$ the bidding strategy $b_{ij}(e_{ij}) = (A_j, p_{ij})$ with $\tilde{a}_j^l = a_j^l\ \forall l \in L, p_{ij} = c_{ij}(e_{ij}, \tilde{A}_j)$ (truth telling with respect to configuration and price) $\forall i \in \tau(j), \forall j \in \sigma(s)$ is a weakly dominant strategy.*

Proof of Theorem 1. Lemma 1 shows that once service providers are allocated they are not able to influence their reward as π is independent from the announced attribute values and prices. Nevertheless, bids have an impact on the chance of being allocated. Assuming without loss of generality that service provider s only owns one service z with a configuration A_z. A service provider s wants to be allocated iff $\pi^s > 0$.

$$\mathcal{U}^*(e_{iz}) > \mathcal{U}^*_{-z} \Leftrightarrow \pi^s > 0$$

$$\mathcal{U}^*(e_{iz}) > \mathcal{U}^*_{-z} \Leftrightarrow p_{iz} + \left(\tilde{\mathcal{U}}^*_z - \mathcal{U}^*_{-z}\right) - c_{iz}(e_{iz}, \tilde{A}_z) > 0$$

$$\mathcal{U}^*(e_{iz}) > \mathcal{U}^*_{-z} \Leftrightarrow p_{iz} + \tilde{\mathcal{U}}^*_z > c_{iz}(e_{iz}, \tilde{A}_z) + \mathcal{U}^*_{-z} \quad (11)$$

A possible solution that satisfies (11) is truth-telling with respect to configuration and price such that $p_{iz} = c_{iz}(e_{iz}, \tilde{A}_z)$ and $\mathcal{U}^*(e_{iz}) = \tilde{\mathcal{U}}^*_z$. As shown in Lemma 1 service providers have no control about their reward once they are allocated which implies that any other possible solution besides truth-telling that satisfies (11) is not better than truth-telling. Hence, reporting attribute values $a^1_z, \dots, a^l_z$ truthfully meaning that announced values are actually realized through execution such that $a^l_z = \tilde{a}^l_z \; \forall l \in L$ and consequently $\mathcal{U}^*(e_{iz}) = \tilde{\mathcal{U}}^*_z$ as well as $p_{iz} = c_{iz}(e_{iz}, \tilde{A}_z)$ is a weakly dominant strategy. □

Theorem 1 shows that the provider's bidding strategy is determined through the mechanism design. Service providers act best (or at least as good as any other alternative) by reporting their services' configurations and internal costs truthfully which is a valuable mechanism property from a requester's perspective. This property assures that although all service providers act self-interested and therefore try to maximize their profit, their dominant strategy maximizes the system's welfare and the requester receives a technical feasible instantiation of the desired complex service at a guaranteed service level. This is a valuable property as it tremendously lowers strategic complexity for service providers and fosters a trustful requester-provider-relationship. It is well-known in literature that incentive compatibility in VCG-based mechanisms may fail in repeated games (Binmore and Swierzbinski, 2000). Nevertheless, in service value networks we observe a high degree of dynamicity with respect to changing service providers, variable costs and network topologies. Thus, each auction setting is different from the preceding one which makes learning from past situations impossible and each game can therefore be treated as a one-shot game.

5 CONCLUSION

We proposed a multidimensional procurement auction for trading composite services in networked economies. We presented a graph-based model that captures the main components and characteristics of service value networks. Based on this model we introduced a mechanism design that enables allocation and pricing of service components that together form a requested complex service. However, auctions for composite services are much more complex than simple procuring auctions, where the suppliers themselves offer a full solution to the procurer. In composite services, this is not the case, as a flawless service execution and therefore the requester's valuation highly depends on the accurate sequence of its functional parts, meaning that in contrary to service bundles, composite services only generate value through a valid order of their components. The allocation is computed based on the requester's score for QoS characteristics of the complex service. At the same time, the mechanism is capable of handling a wide range of aggregation operations for service attributes also supporting rich semantic approaches for dealing with complex non-functional service specifications. Due to the combinatorial restrictions imposed by the underlying graph topology and the absence of capacity constraints, the winner determination problem can be solved in polynomial time which is a crucial issue when it comes to implementing online systems. We furthermore showed that proposed mechanism is individual rational, allocation efficient and incentive compatible with respect to QoS characteristics and prices of service offers. Hence, reporting the true type regarding configuration and price is a weakly dominant strategy for all service providers. This is a valuable property as a it tremendously lowers strategic complexity for service providers and fosters a trustful requester-provider-relationship.

Proposed graph-based scoring auction is evaluated in the *TEXO* use case of the *THESEUS*[2] project. TEXO is a research project, within the Theseus research program initiated by the Federal Ministry of Economy and Technology (BMWi). Within the Theseus program, TEXO contributes to service economy by creating infrastructure components for business webs in the Internet of Services. Via intuitive interfaces and technical systems TEXO addresses the full lifecycle of these services from innovation to productive usage. Addressing these demands requires an interdisciplinary approach to create an integrated platform for the internet of services which supports all phases of the lifecycle. For all stakeholders and participants in such a service value network, innovative business models being as flexible as the network itself are required. Especially the novel requirements for pricing models are addressed by proposed graph-based multidimensional procurement auction. The auction mechanism is capable of allocating and pricing of composite services in an efficient and truthful manner. It enables flexible participation and switching for service providers and at the same time it does not require complete information about configurations, prices and interrelations from the service requester's perspective which makes the mechanism favourable for ad-hoc and situational environments such as service value networks.

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[2] http://theseus-programm.de/front

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